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ROYAL ARMAMENT RESEARCH AND DEVELOPMENT ESTABLISHMENT

RARDE TECHNICAL REPORT 1/81

Erosion Resistant Coatings for Gun Bore Surfaces

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Summary

The service life of present day, high pressure gun barrels is limited by erosion processes in which thermal, chemical and mechanical factors interact in a complex way. The use of refractory metal coatings and other techniques to protect the bore surface is described. Novel coating processes, including CVD (chemical vapour deposition) and PVD (physical vapour deposition), are assessed in terms of suitability for bore protection.

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CONTENTS

1. INTRODUCTION

The firing of a gun causes the removal of material from the bore surface (wear or erosion) and the growth of cracks through the barrel wall (fatigue). The term 'wear' is now usually restricted to the mechanical removal of material by the passage of the projectile and 'erosion' to the removal of material by the action of hot gases generated by burning propellant. It is useful to define a 'fatigue life' in terms of the number of rounds which may be safely fired and a 'wear life' in terms of the number of rounds fired before ammunition performance becomes unacceptably degraded owing to loss of muzzle velocity and/or increased instability of the projectile in flight. Flight instability may lead to a reduced terminal performance and a loss of accuracy.

For large calibre, direct fire tank guns erosion is often more significant than either wear or fatigue because it can develop rapidly under present day conditions when high flame temperature propellant is burnt at a high pressure to obtain the requisite projectile performance.

Historically the service lives of such guns have been determined alternately by fatigue and wear/erosion. During the Second World War wear determined the service life, but fatigue subsequently became more important, probably because of higher chamber pressures. Such pressures were necessary to improve performance by increasing muzzle velocity and range, but coupled with the weight reducing designs then being used, they placed a much greater emphasis on the fatigue properties of the gun steel.

This problem has since been largely solved by the use of electroslag refined steels, but such steels do not exhibit a corresponding improvement in wear/erosion resistance. At present the wear life of a gun may be as much as an order of magnitude less than the fatigue life, and for a tank gun the service life may be as short as a few hundred rounds solely because of erosion. Current attention is therefore focussed on achieving a significant reduction in the rate of erosion.

This report deals mainly with one aspect of this work; the development of coatings and deposition techniques. The dominant mechanisms of the wear/erosion process are also described in order to illustrate the hostile nature of the environment created when a gun is fired. This work was first presented at the Institute of Metallurgists Conference 'Environmental Degradation of High Temperature Materials' Douglas, IOM, 1980.

2. THE WEAR/EROSION PROCESS

2.1 Conditions in the Gun Barrel

Many examples of wear in general engineering practice have more than one cause, and the mechanisms involved often interact, thus complicating any attempt at empirical analysis (refs 1, 2). This is true of large gun barrels in which three types of wear/erosion mechanism are possible; mechanical, thermal and chemical (Table 1). The design of the gun system is the major factor in determining the relative importance of these mechanisms, and change in any design parameter concerning the barrel, the propellant, the projectile or the rate of firing could result in a change of dominant mechanism or combination of mechanisms.

TABLE 1

Gun Wear/Erosion Mechanism

Type	Mechanism	Possible Agents
Mechanical	Abrasive	Hard solid particles in gas stream
	Adhesive (frictional)	Swaging action by driving band
	Surface fatigue	Alternating pressure
Thermal	Surface fatigue	Cyclic phase changes, softening
	Surface melting	Exposure to hot propellant gases
	Ablation	Flow of hot gases (gas wash)
Chemical or Corrosive	Contact with hot reactive gases	CO, CO_2, N_2, O_2 etc
	Formation of brittle, unstable layers	Nitride, carbide formation
	Stress corrosion cracking	Oxides of nitrogen in propellant gases
	Corrosion fatigue	Oxides of nitrogen in propellant gases

For a period of several milliseconds while the projectile is accelerating down the barrel, the gun bore surface is exposed to the following conditions:-

a. Flash temperatures up to 3700^{o}K, depending upon propellant composition, which can result in maximum bore surface temperatures between 1100^{o} and 1800^{o}K.

b. Pressure peaks up to 700 MPa.

c. Alternating stresses due to pressure/temperature cycling and associated phase changes in the steel.

d. Mechanical swaging action due to the projectile driving band.

e. Chemical reaction with hot gases produced by combustion of the propellant. These may include CO, CO_2, H_2, H_2O, H_2S, SO_2, N_2, NH_3, NO and CH_4. The short (in total only seconds) firing life of a barrel has led to the belief that more active, transient species, such as H, OH, N, O, NH_2 and HCO etc known to be present contribute to the high surface temperatures by recombining catalytically on the steel surface (ref 3).

f. Abrasive action of solid particles of unburnt propellant or barrel debris.

Subsequent ambient temperature corrosion can also be expected owing to the collection of combustion products and condensates in cracks and crevices produced in the bore surface.

2.2 Effects on the Bore Surface

In rifled bores, maximum erosion usually occurs at or near the commencement of rifling (C of R). This position coincides with maximum exposure to the high pressure and high temperature conditions associated with erosion, whereas wear tends to become more important towards the muzzle (ref 4). Consideration of the damage in the C of R region is likely to be relevant in selecting a method for reducing erosion. The bore surface at the C or R of a fired tank gun is shown in Fig. 1.

FIGURE 1

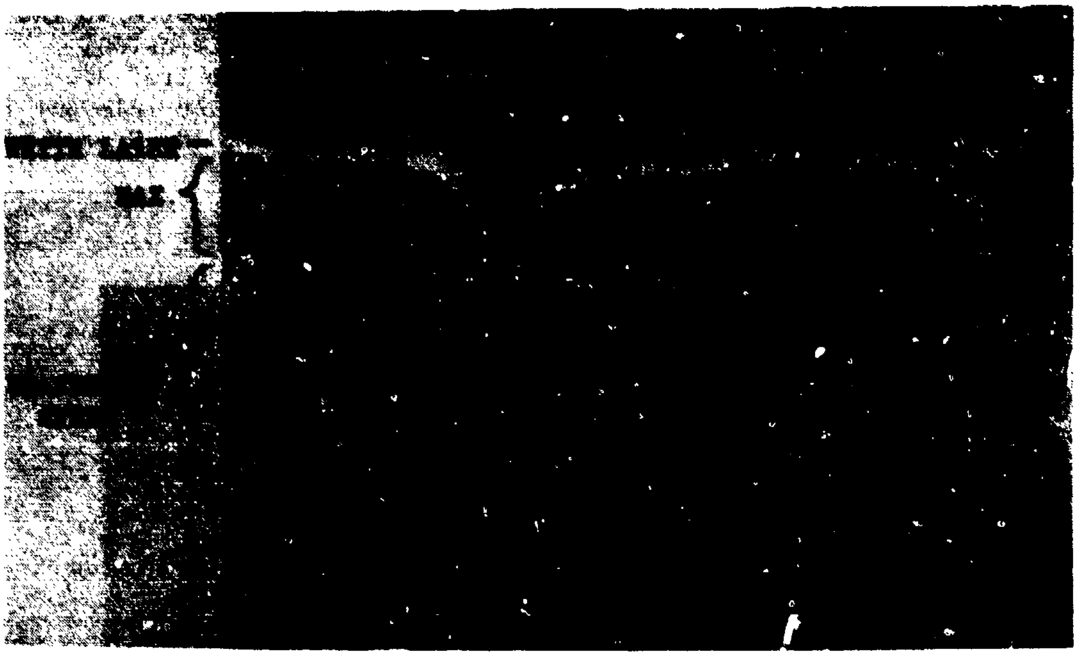
Craze Cracking in a Fired Gun Barrel at Commencement of Rifling (X5)

Alternating thermal stresses induced by successive firings result in tensile rupture of a thin surface layer of steel, forming the characteristic 'craze cracked' or 'heat checked' pattern. The tendency for cracking to occur is reinforced by volume changes accompanying phase transitions when the steel surface temperature passes through the $\alpha \rightleftharpoons \gamma$ critical range. The diffusion of nitrogen and carbon into the steel facilitates retention of austenite and makes cracking more likely.

These thermal/mechanical fatigue cracks may also provide sites for the initiation of chemical reactions involving oxygen, nitrogen and carbon. Cracks once formed can generate particles to erode the barrel or act as hosts to foreign metals (eg copper from a driving band), which can in time lead to intergranular penetration and increasingly catastrophic cracking.

Metallographic examination of any section of a fired gun barrel shows a heat affected zone (HAZ in Fig. 2) at the bore surface (ref 4), which may be overlayed by a 'white layer(s)'. The depth of this zone will vary according to the barrel life and the severity of erosion, but will reach a maximum near the C of R, and gradually reduce towards the muzzle.

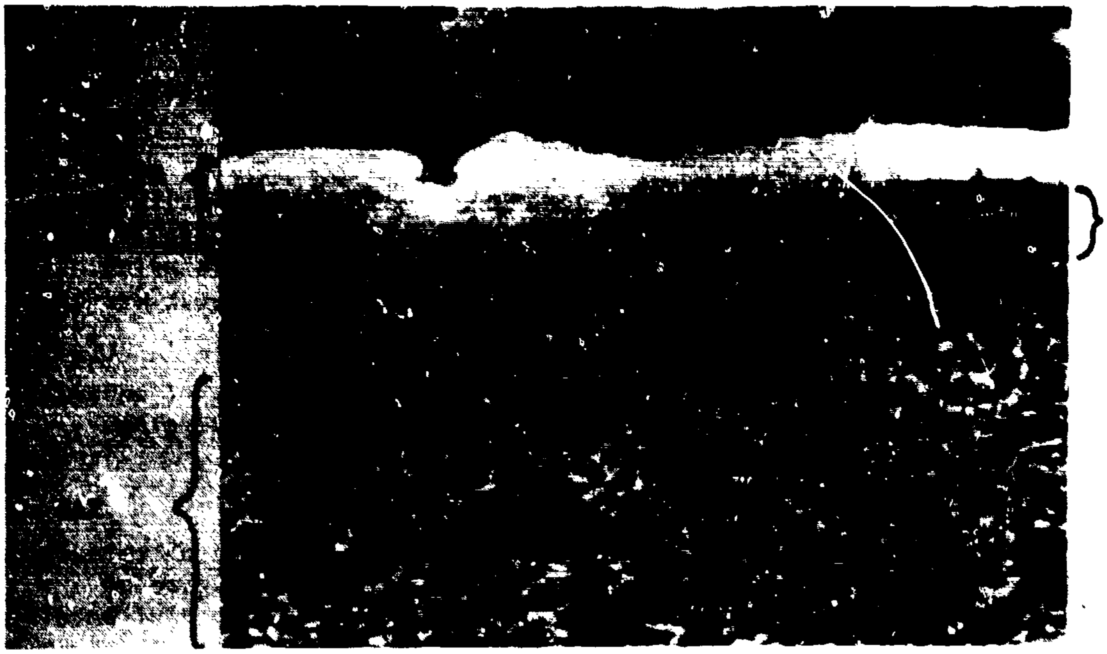
FIGURE 2



Section Through Surface of a Gun Barrel Showing Heat Affected Zone Surmounted by a White Layer (X300)

The altered barrel surface can be resolved into as many as three layers by metallographic etching (Fig. 3). These layers display significant differences in hardness (H_V = Vickers Hardness). The heat affected zone (H_V 700) with a structure similar to that of martensite is found next to the unaltered steel. Above this is a non-etching, featureless structure of stabilised austenite (H_V 300-400) called the soft white layer. Overlaying this is a harder structure containing nitrides and carbides (H_V 500-650) known as the hard white layer (ref 5). These white layers are of great interest since they offer insight into an important erosion/wear mechanism.

FIGURE 3



Electron Optical View of Section Through Gun Barrel Surface Indicating Duplex Nature of White Layer (X5000)

Similar white layers have been produced by heating steel in a reducing carbonaceous atmosphere (eg methane or methane/carbon dioxide), but not by heating in argon or nitrogen (ref 6). Increasing the pressure appeared to encourage formation of the white layers and increase their thickness.

Results suggest that the carbon content and partial pressures of propellant combustion products largely determine the type of white layer formed (refs 5, 6). Higher rates of firing, with longer sustained high temperatures, produce more carbon and favour hard white layer formation, but lower rates of firing promote the soft white layer. On firing, relatively low melting point phases in the white layers facilitate rapid erosion and the underlying steel is liable to undergo further white layer formation.

3. METHODS FOR REDUCING GUN BORE EROSION

Although the attack on the gun bore surface during firing is clearly a combination of thermal, mechanical and chemical effects, it is reasonable to assume that the thermal effects dominate in large calibre weapons. On the basis of this assumption it is possible to identify several distinct approaches to the problem of minimising the heat input to the bore surface:

a. Develop cooler and less erosive propellants.

b. Reduce the effective heat input of existing propellants.

c. Increase the thermal resistance of the barrel surface.

Each of these approaches has received attention during the past two decades as advances in steel technology have placed increasing emphasis on the problem of gun erosion.

3.1 Cooler Propellants

The performance requirements of modern tank guns imply higher muzzle velocities and therefore high force constant propellants with high flame temperatures. Reducing the flame temperature of propellants (ie using cooler propellants) is therefore incompatible with fundamental gun requirements.

An additional drawback of cooler propellants is the possibility of enhanced chemical erosion effects due to changes in the propellant composition.

3.2 Reduced Heat Input

Empirical work in the United States has shown that the addition of certain substances to the propellant can have a marked effect on the degree of erosion. The use of 'Swedish Additive' (finely divided titania plus paraffin wax) can double the life of some gun barrels.

The exact mechanism is still uncertain, but detailed studies have shown that there is a marked reduction in heat transfer to the bore surface when an additive is used. It is possible that the additive interferes with the mechanism of heat transfer through the turbulent boundary layer to the barrel wall.

3.3 Increased Thermal Resistance

Any increase in the thermal resistance of the gun bore surface is usually effected by the use of liners or coatings since alteration of the bulk composition of the steel will cause undesirable changes in mechanical properties. The fitting of liners presents a formidable engineering problem especially for rifled barrels; the usual approach is to co-swage or shrink-fit the liner. These operations are difficult and add considerably to the cost of the finished article.

The deposition of a refractory material on the bore surface to act as a thermal barrier is the classical tribological approach; the bore is protected without significant disturbance of the optimised mechanical properties of the barrel. The selection of such a coating is not a simple matter since the complex geometry and mechanical properties of the rifled barrel place constraints on available deposition techniques and the environment created when the gun is fired demands a high coating integrity. However, recent developments in coating techniques have made the deposition of a wide range of materials possible, and a detailed review of the possibility of reducing wear/erosion by this means is therefore timely.

4. REQUIRED PROPERTIES OF GUN BORE COATINGS

Although it is useful to identify the required bulk material properties, it is incorrect to assume that all such properties will be reproduced in the coating. The mechanical properties in particular may be very different since the coating microstructure is seldom ideal.

The thermal barrier approach implies the deposition of some refractory material which will, by definition, have a high melting point and be chemically inert with respect to the propellant gases. To withstand the pressure/temperature surge during firing and the mechanical effects due to the projectile, the coating material should possess elevated temperature strength and hardness. Certain bulk properties should be closely matched to those of the steel substrate, especially if the coating is thick; these properties include the modulus of elasticity and the coefficient of thermal expansion. Ideally, the thermal conductivity should be low to minimise heat transfer to the substrate during firing, and the material should not undergo any phase change. These requirements lead to a study of the refractory metals chromium, tantalum, tungsten and molybdenum and some of their alloys and compounds.

Excellent adhesion is a primary requirement of any deposition technique in order to prevent gross removal of the coating. Since the barrel substrate geometry is complex the deposition process must possess good throwing power to ensure uniform coverage of both the land and the groove of the rifling. With the thermal barrier technique, coating thickness is clearly important and warrants practical investigation. Porosity is undesirable and the density of the coating material should be similar to that of the bulk material. The microstructure of the coating is also very important. The columnar growth morphology associated with many deposition techniques is known to be particularly unsuitable since crack growth between the columnar grains is likely. This leads to detachment along the coating/substrate interface when the cracks reach the substrate.

The formation of fine equiaxed grains is therefore an essential requirement and can be achieved by ensuring that the deposited atoms have sufficient energy and high surface mobility. Alloy coatings are especially attractive since they provide an alternative means of preventing columnar growth through the co-deposition of atoms of different sizes which usually destroys geometrical symmetry (ref 7). However, close control of the alloy composition may be a problem inside the barrel.

Some coating techniques produce a coating partly diffused into the substrate which is advantageous since it might permit the use of materials whose properties are not closely matched to those of the gun steel. In addition, the absence of a well-defined coating/substrate interface makes detachment of large strips of the coating less likely. A further range of materials, including ceramics, is made available by the use of reactive deposition techniques, although ceramics, which are brittle, cannot be used alone. The possible use of a ceramic interlayer between the substrate and a refractory metal coating is attractive because of the low conductivity of such a combination.

5. REVIEW OF POTENTIAL COATING PROCESSES AND SURFACE TREATMENTS

Although there are a large number of processes which merit consideration (ref 8), the choice is narrowed because of certain constraints imposed by the construction of the gun barrels. The duration of exposure to high temperatures is restricted by the need to minimise detempering of the steel, and the tubular configuration and rifled profile of the barrel make it difficult to use processes in which the coating material originates from a point source. Details of processes which might be used are summarised in Table 2. The most promising involve deposition from the vapour phase and are subdivided into PVD (physical vapour deposition) and CVD (chemical vapour deposition) processes.

TABLE 2

Potential Coating Processes and Surface Treatments

Process or Treatment	Coating System	Typical Coating Structure	Potential Use in Gun Barrels	Disadvantages
Oxy fuel gas spraying	Particles/air	Porous	Unlikely	Limited materials Line of sight
Flame detonation	Particles/air	Dense	Unlikely	Line of sight
Plasma spraying	Particles/air or inert gas	Porous	Large calibre only	Line of sight
Electrodeposition	Aqueous	Microcracked	Chrome plate in limited use	Possible hydrogen embrittlement
	Fused salt	Diffused	Possible	High temperatures
PVD				
Vacuum evaporation	Vacuum	Poor	None	Poor adhesion Line of sight
Sputtering	LP inert gas	Columnar	None	Poor structure
Sputter ion plating	Plasma	Variable	Possible	?
Ion plating	Inert plasma	Variable	Possible	Point source
Reactive ion plating	Reactive plasma	Variable	Possible	Point source
Ion nitriding	Nitrogen plasma	Diffused	Limited	Low m.pt. nitrides usually produced
CVD	Thermally induced	Variable	Possible	High temperature
	Plasma activated	?	Possible	?
Ion implantation	Vacuum	Diffused	Unlikely	Line of sight

5.1 Spraying

Plasma spraying using powder or wire guns may be used to deposit most refractory materials of interest. Although equipment has been developed for use in tubes with internal diameters greater than 100 mm, the porous nature of the coatings usually produced makes it unlikely that spraying by itself would be satisfactory. The flame detonation process is not suitable for coating inside tubes at present.

5.2 Electrodeposition

Ionic deposition from the liquid phase includes chrome plating, a method which has previously been used with some success and is now being reassessed. Unfortunately the coating usually obtained is highly stressed and the resulting microcracks lead to spalling. The possibility of producing coatings with a reduced inherent stress is being investigated.

Most other metals of interest are not easy to deposit except by resorting to fused salts (ref 9). This process may be carried out at temperatures in the range 550-850°C by using eutectic mixtures of alkali metal fluorides, chlorides or fused borates. The boriding of steel produces a very hard surface which could be of value because of the formation of boron nitride by subsequent nitriding (see Section 5.3.3) (ref 10).

5.3 Vapour Deposition

The development of these processes has been spurred by the environmental hazards associated with plants used for the electrodeposition of certain metals (eg cadmium and chromium).

5.3.1 PVD - Vacuum Evaporation and Sputtering

Vacuum evaporation is a well established process in which a relatively volatile metal (eg aluminium) is evaporated in vacuo from a crucible (which is effectively a point source) and deposited on nearby substrates. The deposition is strictly line of sight, that is little or no deposition is possible around corners, along edges or in deep holes, but some improvement in throwing power (ability to penetrate holes, cover rifling etc) is obtained by admitting low pressure inert gas to scatter the evaporant (ref 11). Sputtering is also a well known process. It originally used a dc glow discharge to bombard a target of the coating material with energetic gas ions (usually argon) so that small fragments were ejected and deposited on the nearby substrate. This process was slow and like vacuum evaporation did not usually give well structured coatings.

Both processes have been improved dramatically by subjecting the substrate surface to a glow discharge plasma during coating. This may be achieved in various ways: by substrate biasing to attract some ions from an existing plasma used for sputtering, through the use of radiofrequency or magnetron discharges, or by ion injection or hollow cathode devices which increase plasma ionization (ref 12). The exact mechanism of plasma/substrate interaction is not clear, but plasma treatment has been used, for example, to

increase the surface energy of polymeric materials prior to bonding (ref 13), and by BR for rail cleaning (ref 14). A simple explanation is that ion bombardment or another energy transfer process from free radicals or excited species in the plasma, gives deposited atoms sufficient energy to ensure the formation of a fine grained coating structure.

5.3.2 PVD - Ion Plating and Sputter Ion Plating

When vacuum evaporation is combined with ion bombardment from a glow discharge the process is called ion plating, although it is now certain that the observed coating rates cannot be explained quantitatively in terms of deposited metallic ions (ref 15). We have obtained ion plated coatings on flat surfaces using an electron beam evaporator for various metals, including tungsten, titanium and chromium, but present indications are that the throwing power of the process is insufficient for coating gun barrels using point source evaporation techniques. In sputter ion plating it is possible to use an extended source in the form of a rod or wire placed along the axis of the barrel. This has been shown to be effective in covering the rifled substrate with tantalum or tungsten, and the process has the advantage that by biasing or some other technique it is possible to control the specific energy transfer from the plasma, so that a dense coating may usually be obtained; it is also possible to deposit alloys.

5.3.3 PVD - Reactive Ion Plating and Ion Nitriding

In addition to metals, a whole range of refractory nitrides, carbides, oxides, sulphides etc may be obtained as coatings by introducing a reactive gas into the plasma. Steels of the type used in gun barrels will react directly with a nitrogen containing plasma and the process (ion nitriding) is now used for surface hardening (ref 16). Although it seems that the nitrided surface so produced cannot withstand the thermally erosive conditions experienced when a gun is fired, it could be beneficial since it renders the substrate chemically inert to hot nitrogen in the propellant gases before coating. Surface stability might be enhanced by the presence at the steel surface of a diffused layer of an element such as boron, which forms a refractory nitride.

5.3.4 CVD

Chemical vapour deposition processes use a volatile metallic compound which is pyrolysed, often in the presence of hydrogen, to produce a coating on a heated substrate (ref 17). The flow system used seems to be particularly suitable for gun tubes and there is no limitation imposed by the throwing power of the process. The deposition of tungsten from tungsten hexafluoride has been studied in some detail (ref 18), but as with the fused salt process, the high temperatures required will cause substrate detempering.

There are two possible ways of overcoming this problem. The first is to use metallic volatiles, especially organometallics, which pyrolyse at lower temperatures. Interest has recently been revived in the use of carbonyls to deposit molybdenum and tungsten, but carefully controlled additions of steam and hydrogen or possibly carbon dioxide are necessary to avoid oxide or carbide contamination (ref 19). A second method of more general application is largely to abandon substrate heating as the method of initiating pyrolysis or reducing the metallic volatile and to supply the necessary activation energy by some other route. The most obvious approach is to repeat what has been

done with PVD processes and use a plasma derived from a glow discharge as an energy exchange medium. Such a procedure would also confer many of the advantages of PVD processes including sputter cleaning, yet still retain the high throwing power of CVD.

A disadvantage of many CVD processes is that they tend to produce coatings exhibiting marked columnar growth. This may be associated with the quiescent substrate conditions produced using low vapour flows at near atmospheric pressure in the presence of substrate induced convection. Mechanical methods (substrate rotation, impacting balls or rollers) may be used to generate turbulence and thereby increase the number of crystal growth sites required for a fine grain structure. Chemical methods of grain refinement, for example introducing a small proportion of methane into a metal halide/hydrogen mixture, rely on a minor constituent, in this case a carbide, with a different crystalline structure or lattice parameter.

5.4 Ion Implantation and Hybrid Processes

Ion implantation uses an electric field (10 to 200 keV) to accelerate ions in a hard vacuum to high velocities (ref 20). Since it is strictly a line of sight process it would not be applicable to gun barrels.

Another approach is to consider the subsequent treatment of deposited coatings to improve their structure. This is attractive because several existing processes, including plasma spraying and electrodeposition (for chromium), produce coatings with defective structures. It may be possible to employ fast, high intensity thermal treatments which improve the coating structure but leave the substrate largely unaffected. Promising techniques include scanning the coated surface with laser (ref 21) or electron beams, or exposure to a sufficiently energetic plasma. Initial experiments with laser glazing have shown the importance of ensuring complete surface treatment by the focussed beam and of carrying out the process in a completely inert atmosphere (chromium embrittles readily in the presence of nitrogen).

6. ASSESSMENT

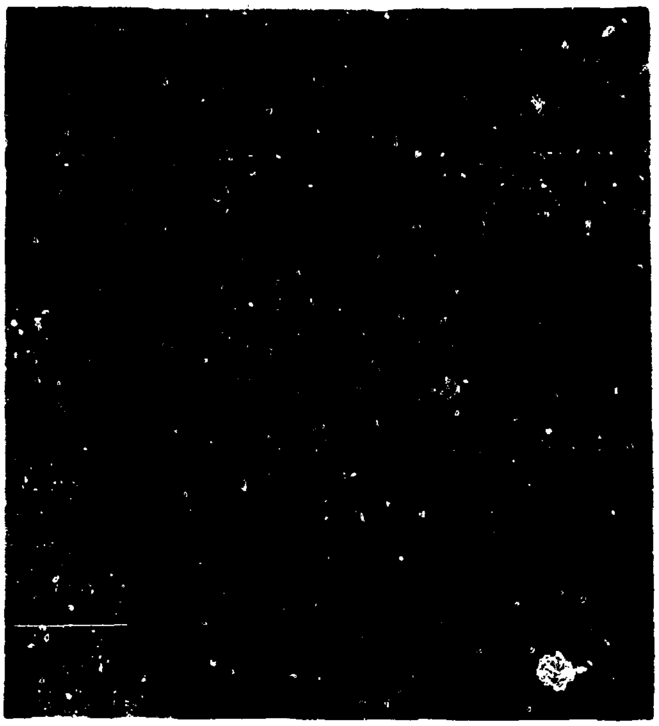
Firing large guns is an expensive procedure and many rounds are necessary to determine wear rates. Clearly it is not possible to assess all the coatings derived by every possible process in this way. In addition, several novel processes are only able to coat small flat samples at present. It has therefore been necessary to establish several small scale assessment procedures, beginning with small coated flat test plates (coupons) and working up through coated nozzles to a 30 mm stub barrel firing system. The advantage of this method of operation is that unsatisfactory coatings can be discarded early. It is difficult to mimic the extreme thermal conditions produced in a gun barrel on firing; this has been attempted by using a plasma jet for flat coupons and a vented vessel system for nozzles.

6.1 Plasma Test

The plasma jet test is shown in Fig. 4. It was developed in the USA for the space programme to assess ablative coatings for re-entry vehicles (ref 22). The method used at RARDE is a dynamic one in which a plasma torch traverses a series of coated (and uncoated) test coupons at a measured velocity. Two

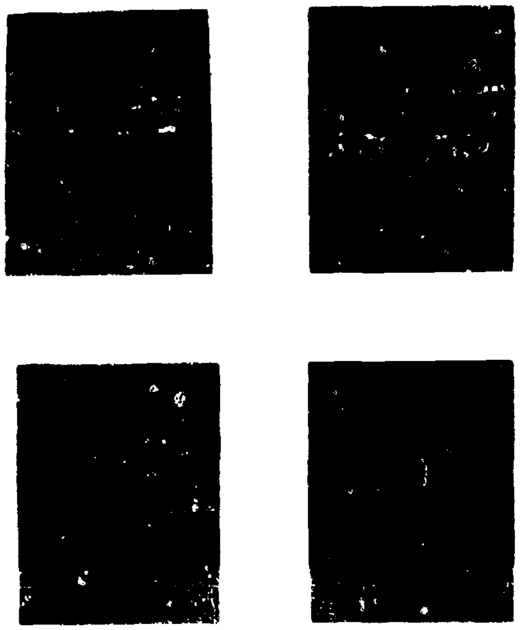
experimental variables, the power generated in the torch P (product of volts and amps) and the traverse velocity v, may be related to the distance Z traversed by the plasma jet across the coupon surface before pyrolysis of the coating begins. Coatings may pyrolyse in several ways, although melting is the most likely. Each coated coupon may be used at least twice; the traverse direction is reversed the second time (Fig. 5).

FIGURE 4



The Plasma Testing of Coated Coupons

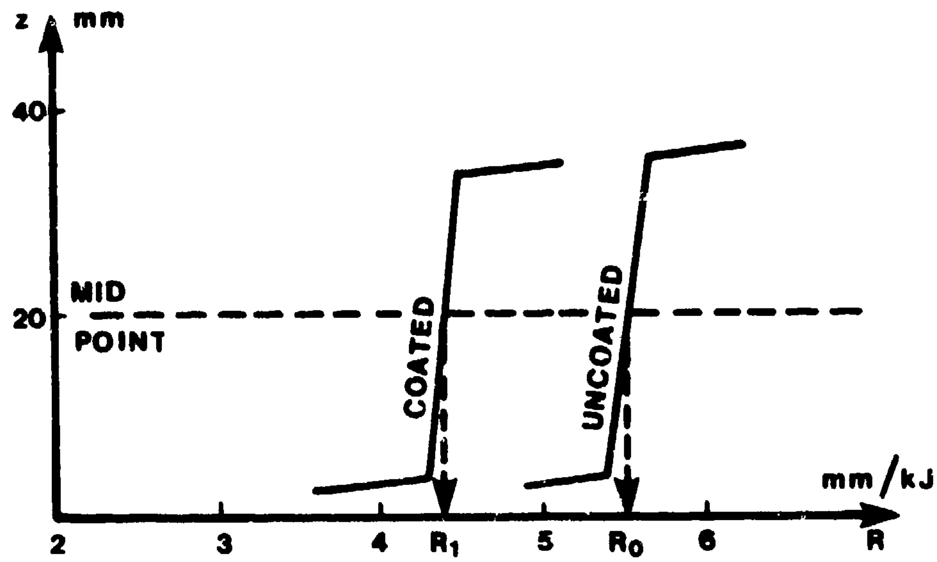
FIGURE 5



Plasma Tested Coupons

An expression of the form $Z = HR$ may be deduced, where H is the thermal energy required from the plasma jet to pyrolyse the coating and R is the ratio v/P, with a correction factor to allow for small variations in coupon mass. This expression is valid for Z values of about half the test coupon size. Corresponding R values may be determined from graphs for the coating under test R_1, and for either an uncoated or a standard chrome plated coupon R_0 calibrated previous (Fig. 6). The ablation factor A of the coating, defined as the ratio of heat inputs required to produce the same erosion for the coating and for the standard, is found from $A = H_1/H_0 = R_0/R_1$.

FIGURE 6



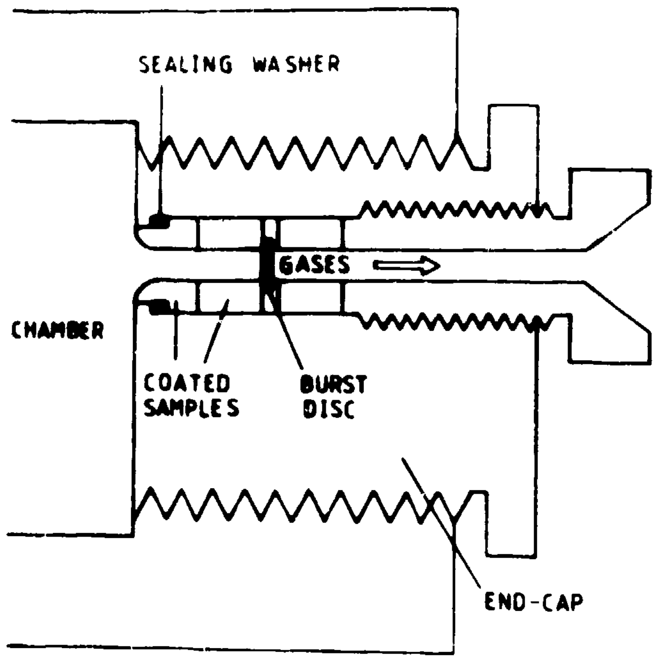
Plasma Test: Comparison of Coated and Uncoated Coupons

This technique is not always practicable or necessary; it requires many identically coated coupons to establish the Z versus R graph. In order to determine ranking order, it is sufficient to traverse several (usually five or so) differently coated coupons simultaneously and measure the corresponding Z values. Repeated experiments, each including a standard coupon, allow the assessment of many coatings remarkably quickly and ablation factors may be deduced by interpolation.

6.2 Vented Vessel

The vented vessel simulation test has been developed to assess the erosion resistance of coated steel nozzles when exposed to hot propellant gases. The vessel is a cylindrical steel chamber with removable end caps and has an internal volume of 0.7 litres. The steel samples, which have a vent diameter of 12.5 mm, are mounted in one end cap as shown in Fig. 7. The samples are used in pairs to restrict individual length. A quantity of propellant is ignited in the chamber by means of an initiator mounted in the opposite end cap. As the propellant burns the pressure inside the chamber increases until at approximately 154 MPa the copper burst disc ruptures and hot gases stream out through the vent, eroding the surface. Variations of this technique have been used in the study of propellant chemistry and erosion effects since the beginning of this century (refs 23, 24).

FIGURE 7



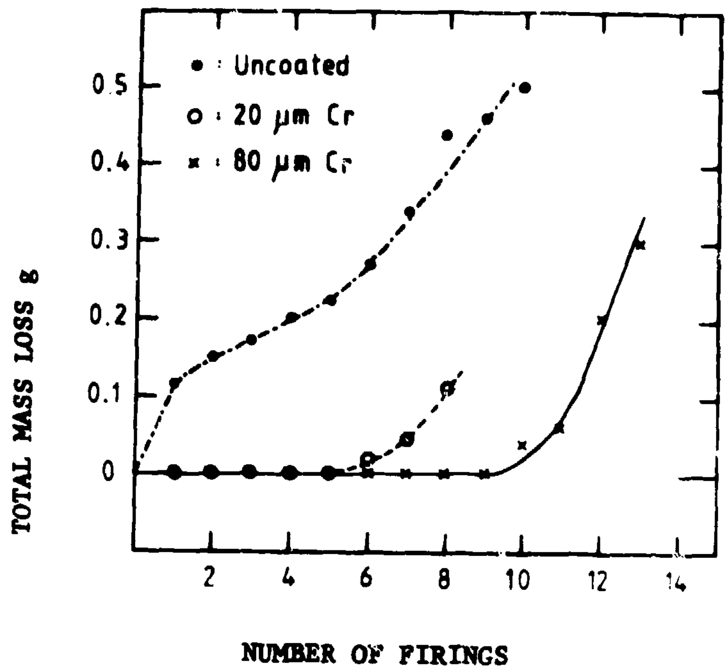
Location of Steel Samples in the End Cap of the Vented Vessel

Erosion of the steel nozzles is monitored by weighing them after each firing. The progressive sample mass loss has been found to be reproducible and the test provides a means of comparing the erosion resistance of coatings produced by various deposition techniques. The progressive mass loss for uncoated and chromium plated nozzles is shown in Fig. 8.

The erosion of the uncoated nozzles is characterised by a large removal of material during the first firing (due to the smoothing out of machining marks) followed by fairly uniform erosion with each successive firing which gradually increases as gas wash channels are etched in the steel.

The situation is very different for the electroplated nozzles which do not display any mass loss over a significant number of firings. Failure when it occurs is related to the microcracked nature of the chrome plate and large strips of the coating are suddenly torn away. The gas wash effects are then greatly enhanced and subsequent erosion of the exposed steel is more severe than for an uncoated nozzle. The number of firings before failure of the coating occurs is dependent on the thickness of the chrome plate (Fig. 8). The number of firings before significant mass loss or exposure of substrate steel occurs can therefore be used as a measure of erosion resistance.

FIGURE 8



Erosion of Uncoated and Electroplated Chromium Samples in the Vented Vessel Test

It is not expected that the spalling associated with chrome plate will be the failure mode for all types of coatings. In some cases gradual erosion is more likely and the slope of the line of progressive mass loss will be more significant than the number of firings.

6.3 30 mm Firing System

Although laboratory simulation techniques provide useful information on coating performance, especially in eliminating non-starters, they are limited because each provides only certain features of the known environment. It is clearly essential to obtain information on the performance of a coating when subjected to the complete environment before making the capital investment required for large calibre trials. Firing trials in small calibre weapons are therefore seen as an important intermediate step between laboratory simulation techniques and full scale firings.

Wear in small calibre weapons is predominantly mechanical in nature and coating performance in such barrels is therefore of dubious relevance to larger calibre weapons. Fortunately the rifled 30 mm barrel provides a useful assessment vehicle, since it is fired at pressures and temperatures approaching those used in large calibre weapons. The normal 3 m length of the barrel prohibits the use of some deposition techniques in their current state of development. The muzzle end is therefore cut off to give a 600 mm long stub barrel which can still be safely fired and is a manageable size for most coating systems. The short length barrel is a valid system for erosion studies,

since it is the erosion at and immediately beyond the commencement of rifling that requires detailed monitoring. A sectioned stub barrel is shown in Fig. 9.

FIGURE 9

Sectioned 30 mm Assessment Barrel Showing Rifled Bore

7. SUMMARY AND OUTLOOK

Despite the increasing importance of gun bore erosion the relative significance of the various erosion mechanisms is not well understood. Although certain empirically derived modifications to the round give worthwhile improvements in barrel life, the development of a thermal barrier coating would be more effective.

Although hard chromium plating is an established technique for barrel protection, its limitations have been identified and present effort is directed towards the deposition of highly adherent refractory coatings with a dense, equiaxed microstructure. Process development, especially involving vapour deposition, is being undertaken to enable such coatings to be applied to gun tubes.

Various assessment procedures have been developed to expose small test samples to aspects of the erosion environment, and these will be used to select the most promising coatings.

Future work will be aimed towards the determination of the precise nature of the erosion mechanism and the development of production techniques for the deposition of preferred coatings in large calibre gun tubes.

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